

14-27-CR

Caires, Valerie

From: durian
To: Caires, Valerie
Cc: bhim.singh
Subject: Re: NASA Lewis Grant No. NAG3-1419
Date: Friday, August 01, 1997 10:24AM

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Dear Valerie,

Here is the report you've been asking for. I'm faxing a copy to Sheryl Ball and to Kaprice Harris, Emailing a copy to Bihm Singh (PS Bihm: you've seen this already), and mailing a copy to NASA-CASI. There were no patents or inventions connected with this research. Sincerely yours, -DJD

MICROGRAVITY FOAM STRUCTURE AND RHEOLOGY
NASA Lewis Grant NAG3-1419, 12/15/92-12/31/96

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"Summary of Research/Final Technical Report"

OBJECTIVES: To exploit rheological and multiple-light scattering techniques, and ultimately microgravity conditions, in order to quantify and elucidate the unusual elastic character of foams in terms of their underlying microscopic structure and dynamics. Special interest is in determining how this elastic character vanishes, i.e. how the foam melts into a simple viscous liquid, as a function of both increasing liquid content and shear strain rate.

DESCRIPTION: The unusual elastic character of foams will be quantified macroscopically by measurement of the shear stress as a function of static shear strain, shear strain rate, and time following a step strain; such data will be analyzed in terms of a yield stress, a static shear modulus, and dynamical time scales. Microscopic information about bubble packing and rearrangement dynamics, from which these macroscopic non-Newtonian properties presumably arise, will be obtained non-invasively by novel multiple-light scattering diagnostics such as diffusing-wave spectroscopy (DWS). Quantitative trends with materials parameters, such as average bubble size, and liquid content, will be sought in order to elucidate the fundamental connection between the microscopic structure and dynamics and the macroscopic rheology.

SIGNIFICANCE: The utility and fascination of foams are derived largely from the surprising fact that they have a solid-like elastic character in spite of being mostly gas with a few percent volume fraction of liquid, but can nevertheless flow under shear. The physical origin of such unusual rheology in terms of microscopic structure and dynamics is poorly understood and remains a subject of basic scientific interest to physicists, chemists, and chemical engineers. The proposed research promises important new insight into these issues, and could also have significant consequences for our understanding of flow in other dense

randomly-packed systems such as emulsions, colloidal suspensions, slurries, bubbly liquids, and granular materials. Furthermore, all foam applications are empirically based and the proposed research may generate valuable fundamental guidance for the development of materials with more desirable rheology and better stability.

PROGRESS DURING FY1996: During this period we have achieved important goals in both using and developing the multiple light scattering diagnostics. As for the techniques themselves, we have incorporated the effects of refraction and angle-dependent wall reflectivity into our previous diffusion theory prediction for the angular dependence of diffusely transmitted light. And we have verified the result both by random walk computer simulations and by experiments on known suspensions of colloidal spheres and on aqueous foams. We have also developed two new approaches to the theory of diffusing light spectroscopies in order to significantly improve the accuracy with which data may be analyzed for thin samples, for short times, and for cases of strong absorption and anisotropic scattering. As for the physics of foams, we have fully characterized an earlier puzzling observation of short-time nonexponential dynamics in the diffusing-wave spectroscopy signal. By altering the rate of bubble rearrangements, both by application of shear and by change of ambient temperature, we have identified the origin of the short-time dynamics as thermal fluctuations of the liquid-gas interfaces. By two independent analyses we extract a single consistent amplitude for this thermal motion, and can relate it to the macroscopic shear modulus of the foam. These experiments and the new theories will all be important in analyzing the multiple light scattering diagnostic data obtained in flight. On a separate front we also have conducted further simulations of the model of foam rheology I recently introduced based on the approximation of pairwise bubble-bubble interactions. This work gives theoretical insight into the precise nature of how the unusual elastic character of foams melts away with increasing liquid content. It will provide an important benchmark for comparison with the ultimate flight experiments.

PUBLICATIONS:

1. S.S. Park and D.J. Durian, "Viscous and elastic fingering instabilities in foam", *Phys. Rev. Lett.* 72, 3347-3350 (1994).
2. D.J. Durian, "The influence of boundary reflection and refraction on diffusive photon transport", *Phys. Rev. E* 50, 857-866 (1994).
3. D.J. Durian and A.D. Gopal, "Microgravity foam structure and rheology", NASA Conference Publication 3276, 305-308 (1994).
4. D.J. Durian and D.A. Weitz, "Foams", in Kirk-Othmer Encyclopedia of Chemical Technology, 4th edition, J.I. Kroschwitz, ed., Vol. 11, 783-805 (1994).
5. D.J. Durian, "Relaxation in aqueous foams", *Bulletin of the Materials Research Society* 19, 20-23 (1994).
6. D.J. Durian, "Accuracy of diffusing-wave spectroscopy theories", *Phys. Rev. E* 51, 3350-3358 (1995).
7. D.J. Durian, "Penetration depth for diffusing-wave spectroscopy", *Applied Optics* 34, 7100-7105 (1995).
8. A.D. Gopal and D.J. Durian, "Nonlinear bubble dynamics in a slowly driven foam", *Phys. Rev. Lett.* 75, 2610-2613 (1995).
9. D.J. Durian, "Foam mechanics at the bubble scale", *Phys. Rev. Lett.* 75, 4780-4783 (1995).
10. D.J. Durian, "The importance of boundary reflections in the theory of diffusive light scattering", *Optical Engineering* 34, 3344-3345 (1995).
11. M.U. Vera and D.J. Durian, "The angular distribution of diffusely transmitted light", *Phys. Rev. E* 53, 3215-3224 (1996).
12. D.J. Durian, "Two-stream theory of diffusing-light spectroscopies", *Physica A* 229, 218-235 (1996).
13. D.J. Durian, A.D. Gopal, M.U. Vera, and S.A. Langer, "The melting of aqueous foams", NASA Conference Publication 3338, 383-388 (1996).

14. A.D. Gopal and D.J. Durian, "Fast thermal dynamics in aqueous foams", J. Opt. Soc. Am. A 14, 150-155 (1997).
 15. D.J. Durian and J. Rudnick, "Photon migration at short times and distances and in cases of strong absorption", J. Opt. Soc. Am. A 14, 235-245 (1997).
 16. D.J. Durian, "Bubble-scale model of foam mechanics: melting, nonlinear behavior, and avalanches" Phys. Rev. E 55, 1739-1751 (1997).
 17. M. Vera, P.A. Lemieux, D.J. Durian, "The angular dependence of diffusely backscattered light", accepted for publication in J. Opt. Soc. Am. A (1997).
- in progress:
18. P.-A. Lemieux and D.J. Durian, "Influence of anisotropy on DWS", to be submitted to Phys. Rev. E

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